Pioneers

W. A. ATHERTON

7. Alexander Graham Bell (1847-1922): speech shaped current

Institution of Electrical Engineers

What do the following items have in common: the National Geographic Society, the American magazine *Science*, aircraft ailerons, and sheep with four nipples? No, it's not Trivial Pursuit. All were steered into existence by the same man, the inventor of the telephone.

To most people the telephone is one of the greatest inventions of all time. Yet one American newspaper reporter wrote "It is an interesting toy . . . but it can never be of any practical value."

That reporter was not alone in dismissing the new invention. A British official thought it might prosper in the colonies but not in Britain since "we have an abundance of messenger boys". And the great Western Union Telegraph company rejected an offer to buy the patent. "Bell's profession is that of a voice teacher," they observed. "Yet he claims to have discovered an instrument of great practical value in communication which has been overlooked by thousands of workers who have spent years in the field."

The patent Western Union turned down was one of the most lucrative ever issued, for the commercial success of the telephone was as immediate as it was dramatic. Although Bell at first gave lectures and demonstrations to raise much-needed cash (reserved seats cost 50 cents and the first profit was \$149) the success of the telephone made him and his assistant, Thomas Watson, financially secure by 1881. The telephone was by then a mere five years old.

Western Union did, however, get one thing right in their assessment of Bell: he was indeed a teacher of the deaf.

Born in Edinburgh on March 3, 1847, he was christened Alexander. On his eleventh birthday he decided he would like a second Christian name and chose Graham. He and his two brothers inherited a family tradition of teaching elocution. His grandfather had practised in London and his father was the inventor of a phonetic alphabet called Visible Speech. Both Bell's mother and wife were deaf. Helping deaf people learn to speak became his main career.

Bell received his early education from his mother and he became an accomplished pianist. At ten years of age he started school. By the time he entered University College, London at 20, he had taught elocution at Elgin, Edinburgh and Bath.

At university he studied anatomy and biology. But before that, in a letter to his father, he had written up his first scientific research, on the resonant pitches of mouth cavities. As a result of this he was introduced to the work of Helmholtz and gained his first knowledge of electricity.

His brothers died early from tuberculosis. Partly fearing for the health of their remaining son, the family quit Britain for the healthier climate of Canada on August 1, 1870.

In Quebec, Bell taught his father's Visible Speech to deaf pupils and began to teach teachers of the deaf. In 1873 he was appointed professor of vocal physiology at Boston University. Nine years later he became a US citizen, and very proud of the fact he was too.

MAKING SOUND VISIBLE

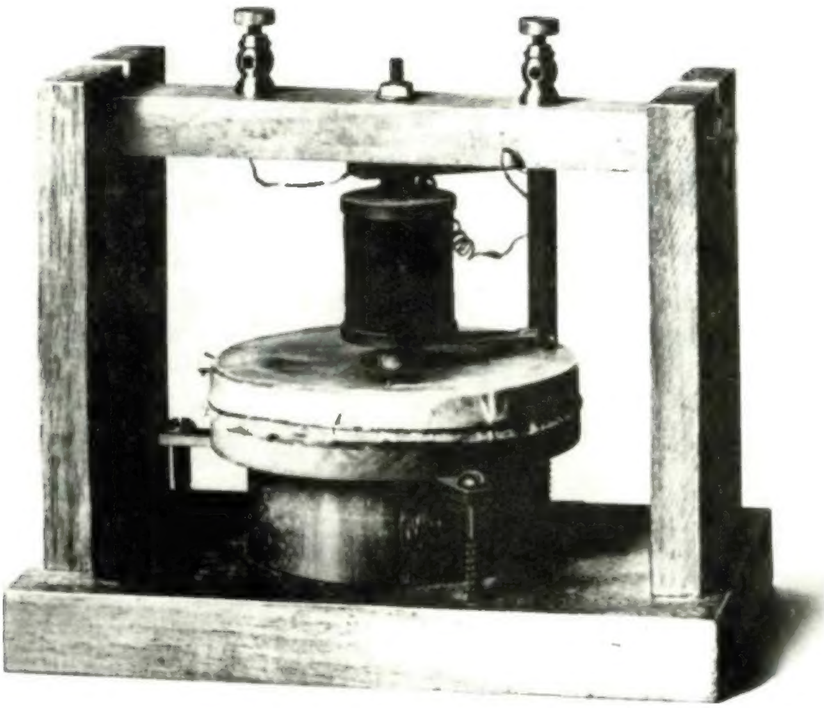
Work with the deaf turned Bell's intellect to all things related to the human voice. In searching for teaching aids he came across the phonautograph, a device with a conical mouthpiece and a stretched membrane which vibrated in response to the voice. The mechanical vibrations were conveyed to a stylus which traced the wave pattern of the voice on to a moving piece of glass blackened with soot.

These and other attempts to make a visual record of a human voice for use as a teaching aid for the deaf were crucial to the invention of the telephone. The step from a mechanical record of voice waves on blackened glass to electrical waves in a wire was the mark of genius. But it did not come in a flash.

For several years Bell had been actively interested in telegraphy and a parallel problem with which he now wrestled was how to use an intermittent electrical current to transmit musical tones via the telegraph. This he thought possible if the vibrations of the air could be somehow reproduced in an electrical current.

In the summer of 1874 he visited his father's home in Brantford, Canada, taking with him a human ear provided by the Harvard Medical School. The idea was to use the ear and the small bones of the ear to make an improved phonautograph: a piece of hay acted as the stylus. The human-ear phonautograph worked!

If the relatively massive bones of the ear



This instrument was used to transmit the first speech sounds electrically in 1875. The parchment diaphragm is attached to a magnetized metallic reed. Piture from AT&T.

An early British instrument, of about 1890: a wall telephone of the National Telephone Company. Picture from British Telecom.

could be vibrated, thought Bell, why not a small piece of steel? The basic concept of the telephone now crystallized, though its practical achievement was still far away. When a practical realization came we can be thankful that the mouthpiece did not need a human ear cut from a corpse.

Whilst continuing his work with the deaf in Boston, Bell had for some time been working on ideas for a multiple telegraph, one which would enable simultaneous signalling of many messages to take place along a single line. By this time he had met a young machinist, Thomas A. Watson, and towards the end of 1874 they worked together at Bell's idea for multiple telegraphy. In that same year Bell explained his telephone idea to the aged Joseph Henry, seeking his advice as to whether to publish the idea so that others could work at it or to finish it himself. Henry told Bell to finish the work himself. When Bell confessed that he did not have the electrical knowledge needed Henry's advice was blunt: "Get it!"

Bell meantime had obtained financial backers: not for the telephone, but for the multiple telegraph, for which his backers had greater hopes. (When the telephone became a success Bell himself insisted that it be part of the agreement.)

A LITTLE ACCIDENT

With his experience of the phonautograph and his mental concept of the telephone, a little accident with the multiple telegraph equipment showed Bell how to achieve his dream of electrical speech.

The multiple (or harmonic) telegraph was to work as follows. At the transmitter and receiver there were tuned vibrating reeds. A reed at the transmitter tuned to a frequency f_1 could, according to the theory, send a pulsed signal which would only be detected by a reed also tuned to f_1 at the receiver. Several reeds tuned at different frequencies (f_1, f_2, f_3, etc) should enable several pulsed signals to be transmitted simultaneously.

On June 2, 1875, in the middle of a baking hot afternoon, Watson and Bell were tuning the reeds when one of Watson's transmitter reeds stuck. The adjustment screw had been screwed too far. To restart Watson plucked it and Bell, at the receiver, gave a loud shout.

Held too hard, the reed had failed to interrupt the current and had produced a continuous sine wave instead. Bell recognised the answer to his dreams. The rest of the afternoon and evening were spent repeating and repeating the discovery.

By the time they parted Bell had sketched out a diagram of the first telephone and begged Watson to try to build it ready for the next evening. "And, as I studied the sketch on my way home to Salem on the midnight train," Watson recalled, "I felt sure I could do so." He did. The next evening the first faint sounds (not speech) were transmitted and received. As yet unintelligible they proved Bell's basic idea.

During the ensuing months, work on the multiple telegraph took enforced priority over the telephone, along with ill health, personal crisis, and teaching duties. An American patent covering the telephone was allowed on Bell's 29th birthday, March 3, 1876. It was actually issued four days later.

On the evening of March 10, intelligible speech was achieved using a 'liquid' transmitter and a tuned-reed receiver. In the new transmitter, designed by Bell and built by Watson, a metal wire attached to a diaphragm was dipped into acidulated water. The water and wire were part of the electrical circuit. As sound waves vibrated the diaphragm, the wire moved up and down in the liquid and so varied the resistance of the circuit. The telephone had arrived.

New transmitters and receivers followed, some using liquids and some employing the relative movements of magnetized coils and pieces of iron. These were demonstrated at the Centennial Exhibition in Philadelphia on June 25, 1876 (the day of Custer's last stand) and impressed all who saw them. Lord Kelvin, who was one of the technical judges, ran the 100-yard length of the gallery from the receiver to the transmitter to congratulate the inventor.

COMMERCIAL SUCCESS

Watson, after some persuasion, resigned his well-paid full-time job to take up full-time work on the telephone. He received a tenth share of the patent. In November, using yet another new design, successful tests were conducted between Boston and North Conway in New Hampshire using a railway telegraph wire, a distance of over 100 miles.

A company was formed in July 1877 two or three months after the first regular telephone lines opened in Boston. Other Bell companies followed swiftly for various reasons, and a reorganization in 1880 created the American Bell Telephone Company.

Western Union meanwhile had set up in competition after the principle of the tele-

phone had become known. Bell sued for infringement of his patents and won. The Bell patents were repeatedly defended in the courts, on about 600 cases, before the Supreme Court eventually upheld all Bell's claims.

Bell meanwhile had married Mabel Hubbard, one of his private pupils and the daughter of one of his financial backers, on July 11, 1877. The marriage was long and happy despite the loss of two of their four children at birth. In August they sailed to Europe to promote the telephone, leaving Watson in charge for over a year. At the time of the wedding a couple of hundred telephones were in operation.

By 1881 both Bell and Watson had moved on to other interests.

Bell continued his absorbing interest in teaching the deaf to speak well. His interest in hereditary deafness led him to studies of longevity and breeding. In 1909, after 20 years' selective breeding, he had a flock of sheep with four or more milk-producing nipples rather than the usual two! Therein lies a tale in itself.

In 1880 France awarded Bell the Volta Prize of 50 000 francs. This he used to establish the Volta Laboratory Association in Washington to work with the deaf. Two years later he conceived the idea for the journal *Science* which began publishing in 1883. In its first eight years Bell and his father-in-law subsidized the journal to the tune of around $100 000.

Bell also helped organize and finance the National Geographic Society and was its president for several years, and he gave $5000 to establish the Smithsonian Astrophysical Laboratory.

For the last 25 years or so of his life one of his main interests was aviation. With a gift of $50 000, he founded the Aerial Experiment Association under whose auspices some of the earliest flights took place in 1908. Bell and the Association held the patent for the design of ailerons for wings and rudders.

He also invented a tetrahedral constructional technique known as space frame, tried to introduce the Montessori educational method to America, and developed an interest in designing hydrofoil boats. One of his hydrofoils gained the world water speed record in 1919 at 70.86 miles per hour.

Amongst the honours Bell received was the freedom of Edinburgh (his birthplace), the opening of the first trans-continental telephone link between New York and San Franscisco in 1915, and the naming of an island after him.

After his death in 1922, at the age of 75, he was buried in a rock tomb on top of a mountain. Every telephone in North America was silent for one minute during his funeral.

Next in this series of pioneers of electrical communication will be Oliver Heaviside.

Tony Atherton works at the Independent Broadcasting Authority's engineering training college in Devon. His book, From Compass to Computer, A History of Electrical and Electronics Engineering, was published by Macmillan in 1984.

68000-family Pascal machine

If you need to decide which computer language to use for your next industrial control system, one of the new breed of Pascal compilers may be ideal.

W.P. STANLEY

Pascal was designed as an easy-to-learn language to teach students how to write programs, which humble beginning it shares with Basic but unlike that language, Pascal enforces the concept of structured programming. To someone who has used Basic, Pascal may appear to be pedantic, it lacks a 'goto' statement for instance, but its strength is that it forces the programmers to understand the true nature of the task before starting to write a program. This means that the program is produced in the correct construction, if not in detail, the first time round as opposed to a poorly concieved core modified by layers of 'goto' statements and extra modifications to get it to work. Even if the time taken to write in both forms is the same, the real cost advantage of Pascal is that the resulting program is self-documenting to a large extent, which leads to easier and faster maintenance.

One of the strengths of Pascal is its comprehensive selection of data types available to the programmer, which now encompass boolean, character (byte), enumerated type, integer, longinteger, hex, longhex, real, string, array, record, devices and files, and pointers. The string functions, so long a weak point in Pascal, have now been enhanced to give similar performance to those in Basic, which has always enjoyed powerful string operators.

Pascal has been limited by some of the same problems as Basić in that it was only available in an interpretive form or with intermediate code output which produced slow executing programs. This tended to preclude control by the programmer as to where variables were held; the compiler or interpreter allocated space in the memory, usually via the stack, or optionally on a reverse stack, the 'heap', without any bearing on the wishes of the programmer. For industrial control, or for any application which wants to poke its nose outside the confines of the operating system, it is essential to be able to access absolute addresses in the memory map to talk to i/o ports. This is now possible in Pascal because the user can specify how the variables are held; on the stack (by default), at an extended (absolute) address, program counter relative, defined in another module or, on 16bit processors, in a c.p.u. register.

A requirement for most programs is the ability to perform simple operations on all relevant classes of data without large processing overheads; things like OR, EOR, AND, NAND and shift. This limitation is overcome in the latest generation of Pascal compilers, which can produce compact 'romable' position-independent object code that is frugal on memory and has a runtime library overhead proportional to the function used. To give figures for one particular compiler, the Omegasoft 68000 Pascal compiler, typical runtime overhead is between 1 and 3Kbytes, with a minimum of about 50 bytes and a maximum of 10K using every function and data type; the compiler efficiency is about 0.4 that of hand-coded assembler but the execution speed is fast. This compares well against a C compiler running on the same operating system; the code efficiency is about the same and the Pascal programs usually execute faster. This is not intended to show that Pascal compilers are 'better' than C compilers, simply that they are comparable and that C code is not automatically the optimum solution.

Another development, which has become more common in the later compilers, is to surround the compiler with a suite of utilities that make the task of converting the program into debugged object code much easier. In the example of Omegasoft Pascal, this takes the form of a easy-to-use linkage creator which asks the user a series of questions about the physical properties of the hardware and produces a small assembler program as a result. This sets all the relevant stack pointers for the main Pascal program and also produces a procedural file which will assemble and link all the needed modules.

A type of utility that has become popular is the interactive debugger, which will allow the programmer to debug software at Pascal line level, to be able to breakpoint to a line